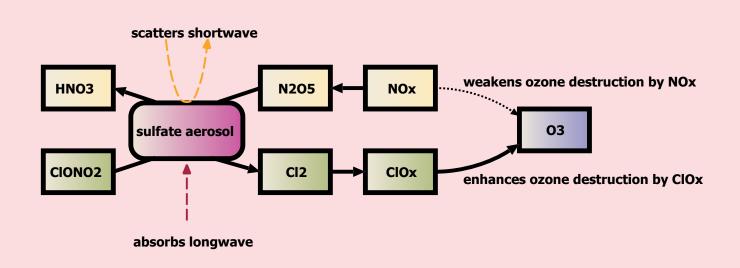
Simulation of Pinatubo aerosols and its impact on stratospheric chemistry by using a CCSR/NIES AGCM

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The stratospheric sulfate aerosol layer can scatter shortwave and absorb longwave, and it can play an important role in the stratospheric chemistry by providing a surface for heterogeneous chemistry.



Schematic diagram showing the effect of sul-

fate aerosols in the stratosphere.

2. The objective of this study

By the eruption of Mt. Pinatubo on June 1991, 12-20Mt of sulfur intruded into the lower stratosphere. The quantity of intruded sulfur is estimated about 100 times larger than the nonvolcanic amount.

Several numerical experiments have been carried out to study the chemical and radiative effect of the 1991 Pinatubo eruption. However, none of them considered the chemical and radiative effect of volcanic aerosols at the same time. The objective of this study is to answer the question "how much is the warming by Pinatubo eruption at the lower stratosphere by considering heterogeneous reactions on the surface of aerosol and radiative effect of aerosol?", by using the radiativechemical-dynamical coupled CCSR/NIES AGCM.

5.3. Temperature anomalies

The change of heating rate caused by aerosols and ozone depletion (c.f., Figure 3) leads temperature change in the lower stratosphere (Figure 4). For about a half year after the eruption, there is no evident discrepancy by the consideration of the heterogeneous reaction on volcanic aerosols. The temperature increases in the midlatitudes and tropics with the maximum value of 1–2K. After January 1992, the warming continues until October 1993 in EXP3. In contrast, the warming rapidly disappears in EXP2. The temperature anomaly of satellite observation has the maximum value of about 1.5K at 30N in October 1991. By considering the heterogeneous reaction on the volcanic aerosol, overestimation of the warming disappears.

Figure 5 shows the residual mean vertical velocities for EXP1, EXP2, and EXP3. There can be seen an enhancement of the vertical current for about one year after the eruption. The maximum value of enhancement is about 0.01–0.03mm/s, corresponding with the temperature increase of 2K.

Wstar [20S-20N, 20-25km]

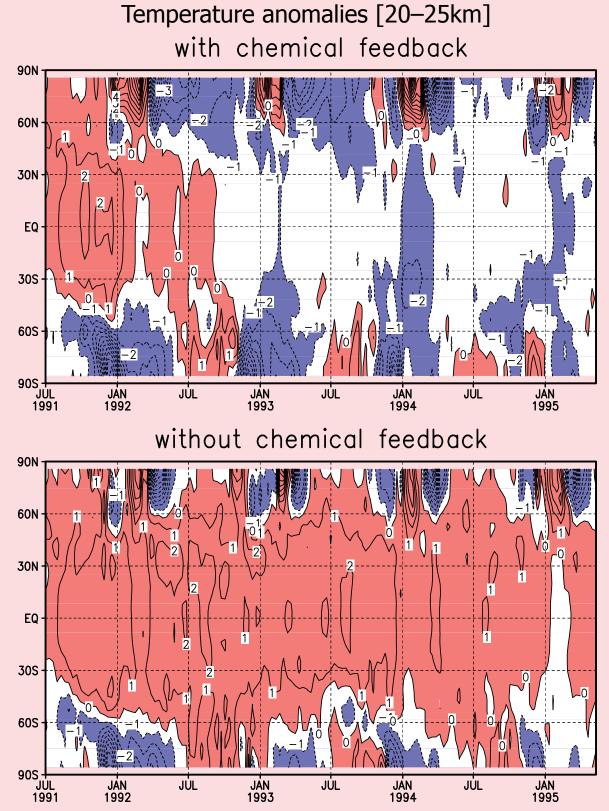


Figure 4: Latitude-time distributions of temperature anomalies for EXP2 and EXP3. Red regions denote the value over 0K, blue regions denote the value lower than

3. Characteristics of the model

Horizontal resolution: T21 (about 5.6 degree) Vertical resolution: 32 levels (about 2km interval, up to 80km)

Radiative Process: DOM + k-distribution, with using 3-D profiles of 20 chemical species (e.g. ozone) and aerosols predicted in the chemical scheme (Online!)

Convective Process: Simplified Arakawa-Schubert (considering tracer updraft/downdraft)

Gravity-wave drag: McFarlane (1987)

Chemical Process: Based on Takigawa et al. (1999), and modified to treat Ox-HOx-NOx-ClOx-SOx chemistry

Gaseous reactions: 85

Chemical species: 36

Heterogeneous reactions: 4

Photolytic reactions: 26

Aerosol properties:

Size distribution: bimodal lognormal distribution based on balloon–bourne observations

Composition: 75wt% sulfuric acid droplet

4. Model scenarios

We conducted three series of numerical experiments with climatological SST. EXP1 was for the background case, and only background aerosols were considered. EXP2 and EXP3 were prepared for the simulation of the 1991 Pinatubo eruption. The difference of EXP2 and EXP3 was the treatment of heterogeneous reactions on the surface of sulfate aerosols. The radiative effect of aerosols on longwave/shortwave was taken into account in all scenarios. In each series, we conducted four members of ensemble experiments.

| | Radiative Effect | Chemical Effect | Surface Emission | Eruption |
|------|---------------------|--------------------|---------------------|----------|
| EXP1 | О | О | О | 0 Tg |
| EXP2 | O | O | O | 17 Tg |
| EXP3 | O | X | O | 17 Tg |
| | | | | |

Design of numerical experiments.

Reference list

Nagashima, T., M. Takahashi, and F. Hasebe, The first simulation for an ozone QBO in a general circulation model, Geophys. Res. Lett., 25, 3,131–3,134, 1998.

Takahashi, M, Simulation of the stratospheric quasi-biennial oscillation using a general circulation model, Geophys. Res. Lett., 23, 661–664, 1996.

Takigawa, M., M. Takahashi, and H. Akiyoshi, Simulation of ozone and other chemical species using a Center for Climate System Research/National Institute for Environmental Studies atmospheric GCM with coupled stratospheric chemistry, J. Geophys. Res., 104, 14,003–14,018, 1999.

5.1. Radiative effect of aerosols.

5.2. Chemical effect of aerosols.

ure 3).

Volcanic SO2 is rapidly converted into sulfate aerosols. The e-folding time of conversion in the model is estimated to be about 45 days, which is about 10 days longer than that observed.

Figure 1 shows the zonal mean column integrated optical thickness for sulfate aerosols. There can be seen a meridional transport of volcanic aerosols. The equatorial values reach the maximum of 0.18 from August to October 1991. The maximum value is similar to that of the SAGE II observation for 550nm (0.18 in the model, 0.20 in the observation).

Volcanic aerosols can change the quantity of chemical species, such as HOx, ClOx, and NOx by heterogeneous reactions on the surface of aerosols. It causes global ozone depletion (Figure 2). Ozone depletion also changes heating rate in the lower stratosphere (Fig-

Relative change of column ozone [%]

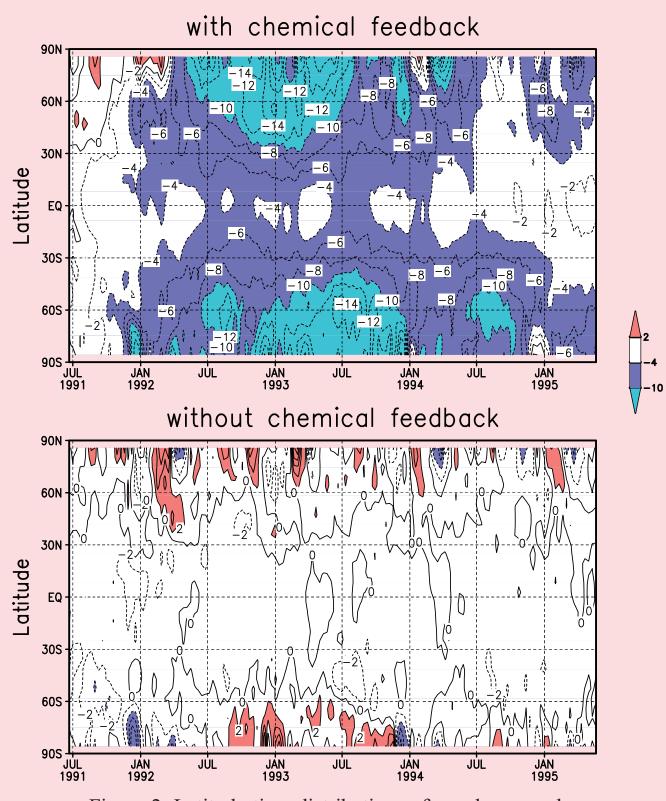
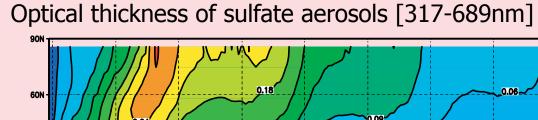


Figure 2: Latitude-time distributions of zonal mean relative change of column ozone by volcanic aerosols for EXP2 and EXP3. Red regions denote the values over +2%, blue and cyan regions denote the values lower than -4%, -10%, respectively.



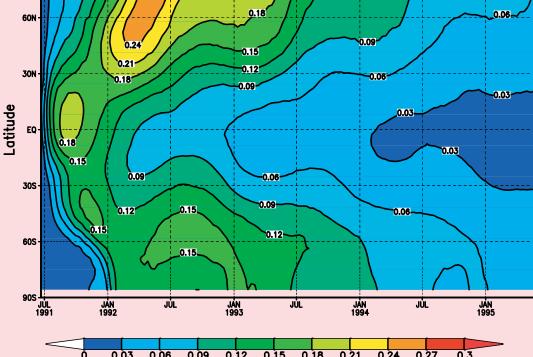


Figure 1: Latitude-time distribution of zonal mean 317nm-689nm averaged optical thickness of sulfate aerosols for EXP2.

Change of heating rate [20–25km, 65N–65S average]

with chemical

without chemcial

Figure 3: Time evolutions of zonal mean anomalies of

heating rate caused by volcanic aerosols at the height of

20–25km. The values are averaged from 65N to 65S.

Each line denotes the ensemble mean of numerical ex-

periments, and colored regions denote the standard devia-

tion of ensemble members.

longwave+shortwave+dynamics

Appendix. The effect of eruption on the QBO

Figure 5: Time evolutions of residual mean vertical ve-

locities for EXP1, EXP2, and EXP3. Each line denotes

the ensemble mean of numerical experiments, and col-

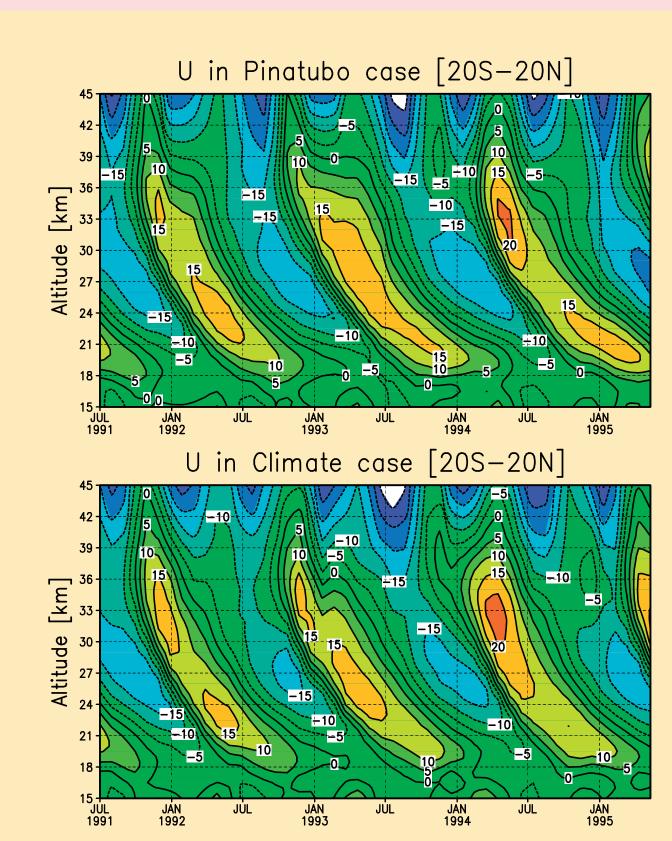
ored regions denote the standard deviation of ensemble

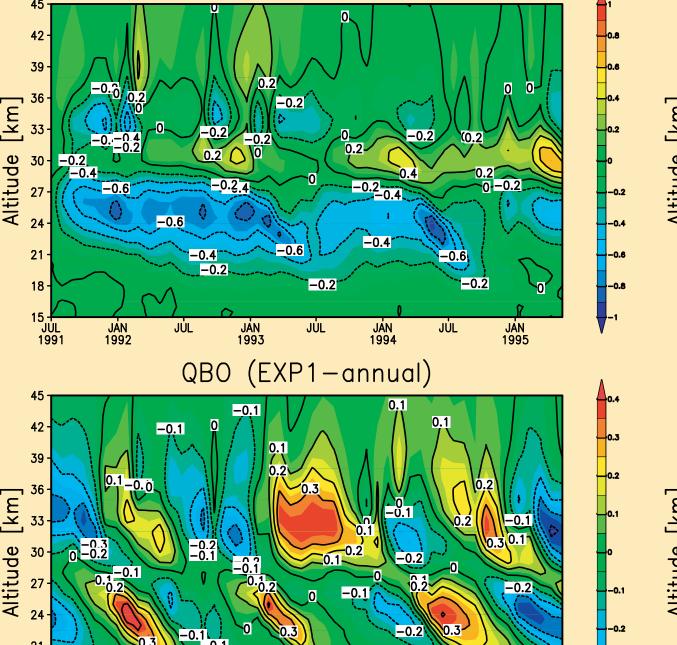
members.

The CCSR/NIES AGCM with a high vertical resolution can reproduce the QBO [c.f., Takahashi 1996] and ozone QBO [c.f., Nagashima et al., 1998]. Supplemental experiments are investigated to evaluate the influence of the 1991 Pinatubo eruption on the QBO by increasing the vertical resolution to 67 layers (approx. 500m interval).

The simulated dynamic feedback is qualitatively similar to that observed. The westerly phase of the QBO is prolonged about 30 days by the 1991 Pinatubo eruption, and corresponding change can be seen in the QBO phase of temperature and ozone. The probable reason for the delay of the QBO phase is the enhanced upward current caused by the aerosol heating in the equatorial lower stratosphere.

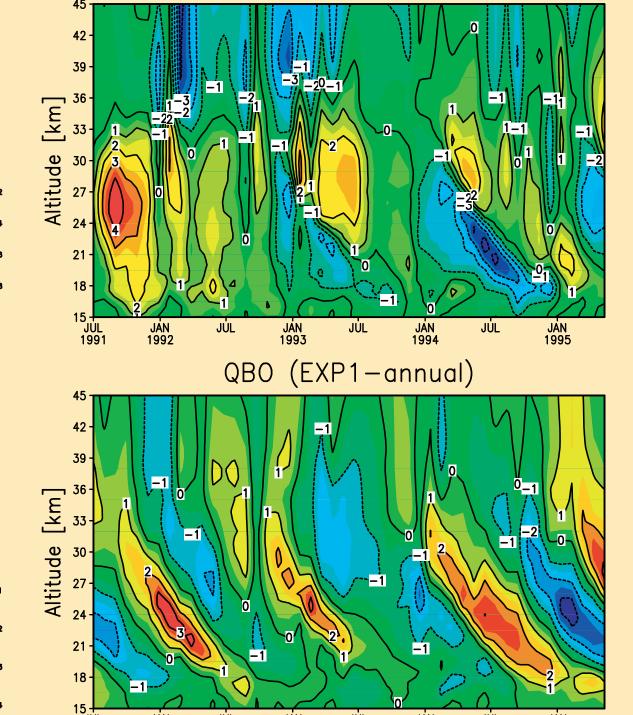
The lower propagation of the easterly phase of the QBO was prevented over 8 months in 1991 in the observation. However, our model could not reproduce remarkable suspension of the lower propagation of the easterly phase in 1991, whereas our model reproduced the temperature increase caused by volcanic aerosols.





Temperature anomalies caused by Pinatubo and QBO [K] [5S-5N]

Pinatubo (EXP2-EXP1)



Ozone anomalies caused by Pinatubo and QBO [ppmv] [5S-5N]

Pinatubo (EXP2-EXP1)